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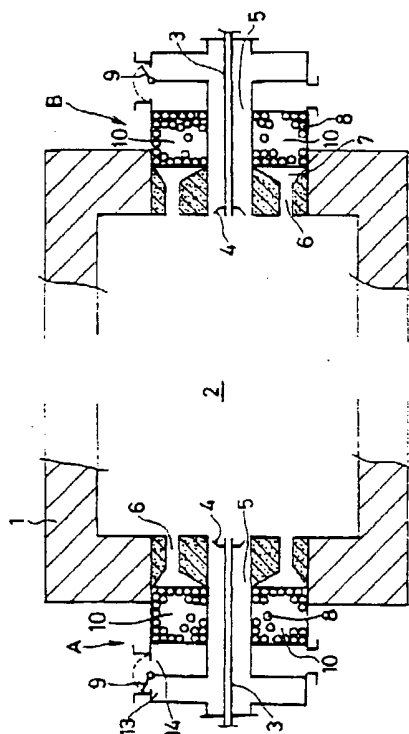
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(54) A regenerative burner, a combustion system and a method of burning

(57) A regenerative burner (A, B) for a combustion chamber (2) and a combustion system comprising a combustion chamber (2) equipped with a pair of the burners (A, B) are described, in which each burner includes a fuel duct (3) for supplying fuel to the chamber and a regenerative preheater (10) containing heat storage material (8) for preheating air for supply to the chamber and alternately for receiving hot exhaust gases (16) from the chamber to reheat its storage material (8), the fuel duct (3) and the preheated-air supply duct (6) opening directly into the chamber at mutually spaced positions so that fuel and air therefrom mix and burn within the chamber, and a cool-air supply duct (5) which opens around the outlet of the fuel supply duct, which also has a stabiliser (4), for supplying cool-air for mixing with the fuel to form a relatively low-temperature stable flame. A method of achieving fuel-in-air combustion is also described.

FIG. 3



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## Description

The present invention is directed to a regenerative burner, a combustion system and a method of burning using the regenerative burner.

A known combustion system is shown in Figure 1 and comprises a furnace 22 equipped with a pair of regenerative burners each having an integrated structure consisting of a combustion section 20 and a regenerative section 21. The burners are used alternately for supplying fuel and air to the furnace and for receiving exhaust gases from it. More specifically, in use, air passes through the regenerative section of one burner where it is pre-heated while the exhaust gas passes through the regenerative section of the other burner where the heat is stored, to be used in turn to pre-heat the intake air. This results in the recovery of waste heat, thereby achieving a high degree of thermal efficiency.

The regenerative burners shown in Figure 1 require that the combustion sections and the regenerative sections of the burners be lined with a refractory material for heat insulation since they are subject to the flow of high temperature exhaust gas and the generation of high temperature flames. Furthermore, since the fuel supply ducts are also exposed to high temperatures at their tips, they deteriorate due to high temperature oxidation. To avoid this, air cooling or water cooling must be used. Moreover, the complicated and large structure of the entire apparatus makes the overall furnace equipment expensive and combustion in the presence of pre-heated air at high temperatures causes large quantities of nitrogen oxides (NOx) to be produced.

An object of the present invention is to provide a burner for a combustion chamber, such as a furnace, which mitigates the above problems.

Accordingly, the present invention provides, in one aspect, a regenerative burner for a combustion chamber, comprising a fuel duct for supplying fuel to the chamber, a regenerative preheater containing heat storage material for preheating air for supply to the chamber and alternately for receiving hot exhaust gases from the chamber to reheat its storage material, and at least one duct for supplying air heated in the regenerative preheater to the chamber, characterised in that the burner is connectable to the combustion chamber, in use, with the fuel duct and the preheated-air supply duct opening directly into the chamber at mutually spaced positions, and in that the burner further includes a cool-air supply duct which opens around the outlet of the fuel supply duct for supplying cool-air for mixing with the fuel to form a relatively low-temperature flame in the combustion chamber in use.

In use of the above burner, fuel is supplied to a combustion chamber, usually a furnace, and burns first with cool air, conveniently a room-temperature supply, at the inlet to the chamber at a relatively low temperature at which NOx production is inhibited. The cool air and low flame temperature also slow the deterioration of the fuel

duct outlet due to oxidation compared with prior art burners.

In addition, once a stable flame is achieved, a flame stabiliser preferably being provided adjacent the fuel duct outlet, combustion of unused fuel continues in the chamber with the aid of the preheated air supplied through the separate duct, preferably several ducts arranged around the fuel outlet but spaced therefrom. These preheated air supplies, preferably injected at high velocities into the furnace, entrain gases, largely inert gas, in the chamber so that they become diluted before mixing with the fuel. This reduces the reaction rate and again lowers the flame temperature compared with that in known furnaces, and again inhibits NOx production.

Once the furnace has reached a running temperature which may be 800°C or higher, the cool-air supply may be stopped and the stabilising flame extinguished, combustion continuing solely in the body of the furnace, or the stabilising flame may be sustained. The requisite air flows to the supply ducts may be regulated by switching means which control the intake air flow to the regenerator and to the cool-air duct and can direct the air wholly to one or the other or can divide the flow between them.

The invention also provides a combustion system comprising a combustion chamber equipped with a pair, possibly several pairs, of regenerative burners as described above, each burner being connected to the chamber with its fuel duct and at least one preheated-air supply duct opening directly into the combustion chamber at spaced positions and the cool-air supply duct opening into the chamber around the fuel supply duct outlet therein, the burners being operable in alternation each to supply air heated in its preheater to the chamber to mix with fuel therein for combustion and to receive exhaust gases therefrom to reheat its heat-storage material,

The regenerative burners are preferably fitted with their heat storage material at least partly located in the combustion chamber wall so that heat from the exhaust gases passing therethrough in the regenerative mode also yields heat to the chamber, increasing the heat-exchange efficiency. The chambers for the heat storage material preferably open into a manifold which serves the plurality of preheated-air supply ducts and is, at least in some embodiments, tapered towards their inlets.

The heat storage chamber may itself be tapered to facilitate its packing with the heat storage material when this is in loose form, for example comprising loose balls of ceramics or metal. Suitable inlets and outlets may be provided for the heat-storage material, preferably enabling the material to be changed without dismantling of the burners from the furnace.

The burner of the invention may include means for providing a pilot light, or burner, in which case it preferably has an auxiliary fuel duct located in the cool-air supply duct and opening near the stabiliser.

A further aspect of the invention comprises a method of achieving fuel-in-air combustion in a combustion

chamber which preferably uses the combustion system described above. More particularly, the invention comprises a method of achieving fuel in-air combustion in a combustion chamber, including the steps of supplying fuel and preheated air to a combustion chamber and enabling them to mix and burn within the chamber, characterised in that it further includes the steps of supplying the fuel and the preheated-air to the chamber at mutually spaced positions such that the flows mix and burn within the body of the chamber and, at least when the combustion chamber is below a temperature at which the fuel and air therein burn spontaneously, supplying cool air to the chamber immediately around the fuel outlet into the chamber and igniting the fuel in the cool air to form a relatively low-temperature flame, a stabiliser preferably being provided adjacent the fuel outlet to stabilise the flame.

Several embodiments of the invention will now be more particularly described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a pair of prior-art regenerative burners installed in a furnace;

Figure 2 shows two views of an important part of an embodiment of a regenerative burner of the present invention, one view showing the burner installed in a furnace;

Figure 3 is an illustration of a pair of the regenerative burners of Figure 2 installed in a furnace;

Figure 4 shows two views similar to Figure 2 of another embodiment of a regenerative burner of the present invention;

Figure 5 is an illustration of a pair of the regenerative burners of Figure 4 installed in a furnace; and

Figure 6 shows two views similar to Figure 2 of yet another embodiment of a regenerative burner of the present invention installed in a furnace.

In the various embodiments of the invention shown in Figures 2 to 6, similar features of the apparatus are indicated by the same references. In general, Figures 2 to 6 show a furnace indicated 2 with a wall 1 and a burner system including a pair of regenerative burners A, B. These burners A, B each include an air supply duct 5 for supplying cool air, at room temperature, which opens directly into the furnace 2 and a fuel supply duct 3 arranged coaxially within the room-temperature supply duct 5 and opening through a flame stabiliser 4 into the furnace 2.

Around the room temperature supply duct 5 are a plurality of ducts 6 for supplying preheated air at a high temperature, these opening directly into the furnace 2 through apertures separate from the room temperature supply outlet. The high temperature ducts 6 receive air

through a common manifold 7 from a regenerative heating section, or regenerator, 10 which also surrounds the room temperature supply duct 5 and is packed with heat storage material 8, such as ceramic or metal balls, honeycomb, fins, meshes or any combination thereof; balls are shown by way of example in the drawings.

The manifold 7 preferably tapers towards its respective outlets to the high temperature ducts 6 while the regenerative section 10 may also taper to its outlet to the manifold 7 as shown in the embodiment of Figure 6. The regenerative section 10 is preferably located at least partly within the furnace wall 1, as shown in the drawings.

An inlet 11 for the heat storage material 8 may be provided, preferably at the top of the regenerator 10 and at a position remote from the furnace 2, as shown in Figure 6 while an outlet 12 for this material may be provided at the bottom.

With reference now particularly to Figures 2 and 3, the room temperature supply duct 5 and the regenerator 10 of each regenerative burner A, B have adjacent air-inlet sections 13, 14 in which flow-switching means 9, such as a valve, operate to allow air to be introduced wholly or partially into the room temperature air supply duct 5 and into the regenerator 10.

In use, the regenerators 10 of the two regenerative burners A, B of the burner system are operated in alternation to supply preheated air to the furnace 2 to effect combustion of fuel supplied through a duct 3 and to receive hot exhaust products from the furnace to reheat their heat-storage material 8. More particularly, when fuel is introduced into the fuel supply duct 3 of the regenerative burner A (in combustion mode), it is mixed with the air injected through the room temperature air supply duct 5 near the flame stabiliser 4 and downstream thereof to initiate combustion. This combustion takes place with the fuel surrounded by fresh air and, since the furnace combustion products (an inert gas) are not mixed with the initial combustion mixture, the combustion is very stable and forms a stable flame region. Also, since the combustion adjacent the flame stabiliser 4 is achieved with the use of cold air rather than pre-heated air, the flame temperature is kept low. Thus, NO<sub>x</sub> production is inhibited and the fuel supply duct 3 and the flame stabiliser 4 are protected from deterioration due to high temperature oxidation.

Once a stable flame has been achieved, while some air may still be introduced into the room temperature air supply duct 5, the remaining air necessary for complete fuel combustion is injected into the furnace 2 through the plurality of high temperature air supply ducts 6. The air is ejected from these ducts into the furnace at a high velocity and entrains the combustion products in the furnace before mixing with the fuel in the region of the stable flame formed adjacent the flame stabiliser 4 so as to sustain combustion. When the furnace temperature becomes sufficiently high, for example about 800 ° C, the flow-switching means 9, if present, is operated to stop the flow of air into the room temperature air supply duct

5, switching it completely to the regenerator inlet 14. At this stage air is fed solely through the heat storage material 8 and equilibrated in the manifold 7 before reaching the high temperature air supply ducts 6 to be injected into the furnace 2 where it interacts with the furnace gas. The air and entrained furnace gas then mix with the fuel which has been injected through the fuel supply duct 3 and which is no longer mixed with room temperature air: the fuel ignites spontaneously at the furnace temperature and combustion is sustained.

As described above, in the present invention, since air and fuel are injected directly into the large furnace volume, unlike conventional combustion methods of injecting air and fuel into a narrow burner space for mixing and burning, the various jets from the injecting sources suck large volumes of furnace gas into them. Therefore, the furnace gas which is inert becomes involved in the combustion zone and greatly lowers the flame temperature which in turn results in a reduced formation of nitrogen oxides compared with that in prior-art furnaces.

The post-combustion exhaust gas in the furnace is discharged through the high temperature air supply ducts 6 of the regenerative burner B which is in exhaust mode, pre-heating its storage material 8. The above combustion and exhaust cycle is alternated through the regenerative burners A and B, for example at a rate of every tens of seconds to every several minutes. In this case, if the temperature of the furnace 2 is kept sufficiently high, for example above about 800°C, combustion stability is ensured by the high temperature and it is not necessary to introduce any more air through the room temperature air supply ducts 5. Also, since the combustion occurs only in the furnace 2, the refractory materials used in ordinary burners to surround the flame are not required. Furthermore, since the heat storage material 8 is partially or wholly located in the furnace wall, no refractory heat-insulating lining is required in the regenerator. These are significant advantages provided by the present invention.

Figures 4 and 5 show an embodiment of the present invention which does not use flow-switching means 9. In this embodiment, when fuel is introduced through the fuel supply duct 3 into the regenerative burner A, it is mixed with air supplied through the room temperature air supply duct 5 near the flame stabiliser 4 and downstream thereof to form a stable flame 18 in the furnace. The amount of room temperature air supplied is preferably small, accounting for less than 15% of the total air introduced into the furnace. The combustion caused by the small amount of room temperature air takes place at low temperatures.

The major combustion reaction then takes place subsequently in the furnace 2 and is a slow combustion involving a large amount of furnace gas 16 before producing high furnace temperatures. This reduces the production of NOx effectively. In more detail while the stable flame 18 is formed and sustained, the high temperature air heated by the heat storage material 8 is injected at a

high velocity through the plurality of high temperature air supply ducts 6. The pre-heated air sucks in and mixes with a large amount of furnace combustion gas which results in a low oxygen partial pressure while combustion takes place; the flame is stabilised by slow combustion and low NOx forming combustion is sustained.

The equipment of Figures 4 and 5 further includes a pilot burner supplied through a pilot duct 15 extending through the room temperature air supply duct 5 and terminating near the flame stabiliser 4. In this embodiment the room temperature air is injected continuously into the furnace 2 irrespective of whether the regenerative burner is in combustion mode or exhaust mode and the pilot burner and the flame stabiliser are therefore always cooled by the room temperature air and protected from deterioration due to high temperature oxidation. Thus, no special cooling system is required. Furthermore, the pilot burner is located in a region in which the pressure fluctuation is very small so that a stable pilot flame can be formed. If the pilot burner is not used, an ignition spark can be generated directly in the flame stabiliser 4 to ignite a small amount of fuel and, after a reliable flame has been established, the amount of fuel can be increased. A flame detector 19 installed in the room temperature air supply duct 5 can give a cooling effect similar to that achieved by the pilot burner 15.

With reference specifically to Figure 6, this shows a regenerator 10 which, as mentioned above, is tapered toward the furnace. This enables the heat storage material 8 to be removed easily from the regenerator 10 simply by removal of the cover over the outlet 12 which allows the material to flow out. To pack the regenerator 10 with the storage material 8, the cover of the outlet 12 is replaced and the cover of the inlet 11 is opened allowing the regenerator 10 to be packed easily with the heat storage material 8 even while the burners are installed in the furnace, without leaving any excessive spaces in the material. In particular, the regenerator 10 can be packed right to the top so that no channel is left here as in some prior art arrangements and the waste heat recovery is made much more efficient.

The various embodiments of the present invention have a number of advantages. (1) The method results in the recirculation of furnace gas before any flames are generated in the furnace interior and while the continuous combustion occurs; as a result, no local hot spots are formed and NOx emission is kept at a low level. (2) A stabilised flame can be maintained with the use of a small amount of air at room temperature and this interacts with the furnace combustion gas before it encounters pre-heated, high temperature air in the furnace. The pre-heated high temperature air jets encounter and mix with the furnace combustion gas as the air is injected into the furnace which lowers the oxygen partial pressure. Since the main combustion progresses while the pre-heated high temperature air is mixing with the furnace combustion gas in a lowered oxygen partial pressure, slow combustion occurs and a low flame tempera-

ture results which effectively reduces the formation of NOx. (3) Since the flame is generated directly in the furnace, a refractory liner is not required to surround the flame and, since the heat storage material is located at least partly in the furnace wall, heat is also stored in the furnace wall itself during the exhaust phase and the temperature of the exhaust gas coming out of the storage material is so low that no refractory heat insulating lining is required. Further, heat loss is minimised. (4) In the embodiments shown in Figures 4 and 5, room temperature air is continuously provided to sustain a stable flame, cooling the fuel supply section, pilot burner, flame detector, etc. As a result no special cooling pipe, etc. is required and equipment cost is reduced. Also, the flame is formed in a region little subject to pressure fluctuation and with a low flow velocity so that there is no concern that the flame may be extinguished. (5) The combustion method of the present invention is not a two-stage combustion method which requires minor combustion in a primary combustion chamber prior to combustion in the furnace proper and therefore no such chamber is required, allowing the total structure to be reduced in size compared with prior art structures. Furthermore, since the stable flame is formed by cold air combustion with a small amount of room temperature air, the flame temperature is kept low and the flame stabiliser and the fuel supply duct outlet are protected from deterioration due to high temperature oxidation. This is true at least while cold air is being supplied but also when it is stopped since, at this stage, combustion occurs within the body of the furnace rather than adjacent the stabiliser, enhancing the reliability of the equipment. In addition, since the heat is effectively stored in the furnace wall, a very high degree of thermal efficiency is achieved. (6) In the embodiments shown in Figures 4 and 5, the stability of the main flame at low temperatures is ensured by a stable flame adjacent the flame stabiliser even without the switching of air from the room temperature supply duct to the high temperature supply ducts as the furnace temperature varies: low NOx production can therefore be sustained irrespective of the furnace temperature. (7) The overall structure is simpler than prior art structures and equipment costs are reduced comparatively. (8) In the embodiment of Figure 6 the packing and replacement of the heat storage material can be performed very easily while the burners are installed in the furnace, making the burners easier to use. (9) Since no "clearance" (excessive spacing) is formed in the regenerator at the top of the heat storage material, channelling is prevented which results in very efficient waste heat recovery. (10) The tapered regenerator eliminates any wasted space when the heat storage material is packed. (11) Given that the heat storage material is easily exchanged, even dirty exhaust gas which could not be used in conventional burners, can be used in the regenerative burners of the present invention.

## Claims

1. A regenerative burner (A, B) for a combustion chamber (2), comprising a fuel duct (3) for supplying fuel to the chamber, a regenerative preheater (10) containing heat storage material (8) for preheating air for supply to the chamber and alternately for receiving hot exhaust gases (16) from the chamber to reheat its storage material, and at least one duct (6) for supplying air heated in the regenerative preheater to the chamber, characterised in that the burner is connectable to the combustion chamber, in use, with the fuel duct (3) and the preheated-air supply duct (6) opening directly into the chamber at mutually spaced positions, and in that the burner further includes a cool-air supply duct (5) which opens around the outlet of the fuel supply duct for supplying cool-air for mixing with the fuel to form a relatively low-temperature flame in the combustion chamber in use.
2. A regenerative burner according to Claim 1, further including a flame stabiliser (4) adjacent the fuel duct outlet.
3. A regenerative burner according to Claim 2, further including an auxiliary fuel duct (15) extending through the cool-air supply duct (5) and opening near the flame stabiliser (4) to supply fuel for a pilot burner.
4. A regenerative burner according to Claim 1, Claim 2 or Claim 3, characterised in that a chamber of the regenerative preheater which contains the heat-storage material opens into a manifold (7) connected to a plurality of preheated-air supply ducts (6), the system being connectable to the combustion chamber with the said plurality of ducts opening thereinto at positions spaced around the fuel duct opening.
5. A regenerative burner according to Claim 4, characterised in that the manifold (7) tapers towards the preheated air supply ducts (6).
6. A regenerative burner according to any one of the preceding claims, characterised in that the heat storage material (8) is housed in a chamber which tapers towards the at least one preheated-air supply duct, the heat storage material comprises separate bodies packed into the chamber, a heat-storage material inlet (11) is provided at the top of the chamber and a heat storage material outlet (12) is provided at the bottom of the chamber.
7. A regenerative burner according to any one of the preceding claims, characterised in that the cool-air supply duct (5) and the regenerative heater (10)

- have cool-air inlets (13, 14) and flow-switching means (9) are provided which are capable of switching the cool-air inlet flow partly or wholly between the two inlets.
8. A regenerative burner according to any one of the preceding claims, characterised in that constituent parts of the burner are provided in a body which can be fitted to the wall (1) of a combustion chamber (2) with the cool-air duct (5) and the or each preheated-air duct (6) opening through the wall into the chamber at spaced positions and the fuel duct (3) opening through the cool-air duct.
  9. A regenerative burner as claimed in Claim 8, characterised in that the body is insertable in an aperture in the combustion chamber wall (1) with the regenerative preheater housed at least partly in the wall of the combustion chamber.
  10. A combustion system comprising a combustion chamber (2) equipped with a pair of regenerative burners (A, B) according to any one of Claims 1 to 9 each connected with its fuel duct and at least one preheated-air supply duct opening directly into the combustion chamber at spaced positions and the cool-air supply duct opening into the chamber around the fuel supply duct outlet therein, the burners being operable in alternation each to supply air heated in its preheater to the chamber to mix with fuel therein for combustion and to receive exhaust gases therefrom to reheat its heat-storage material.
  11. A combustion system according to Claim 10, characterised in that the heat storage material (8) is housed at least partly in the wall (1) of the combustion chamber (2).
  12. A method of achieving fuel-in-air combustion in a combustion chamber, including the steps of supplying fuel and preheated-air to a combustion chamber and enabling them to mix and burn within the chamber, characterised in that it further includes the steps of supplying the fuel and the preheated-air to the chamber at mutually spaced positions such that the flows mix and burn within the body of the chamber and, at least when the combustion chamber is below a temperature at which the fuel and air therein burn spontaneously, supplying cool air to the chamber immediately around the fuel outlet into the chamber and igniting the fuel in the cool air to form a relatively low-temperature flame.
  13. A method according to Claim 12, further including the step of providing flame stabilising means adjacent the fuel outlet for stabilising the low-temperature flame.
  14. A method according to Claim 12 or Claim 13, characterised in that a minor proportion of the air required for complete combustion of fuel supplied to the combustion chamber is supplied as cool air around the fuel outlet throughout the period of operation of the chamber, whether or not the combustion chamber temperature is above the spontaneous ignition point.
  15. A method according to Claim 14, characterised in that the proportion of cool air supplied is up to substantially 15% of the total volume of air required.
  16. A method according to Claim 12 or Claim 13, characterised in that when the combustion chamber temperature is at or above the temperature at which fuel burns spontaneously within it, the cool-air supply is stopped.
  17. A method according to Claim 16, characterised in that the cool-air supply is stopped when the chamber temperature is above about 800°C.
  18. A method according to any one of Claims 12 to 17, carried out with the use of a regenerative burner according to any one of Claims 1 to 9.
  19. A method according to any one of Claims 12 to 17 carried out with the use of a combustion system according to Claim 10 or Claim 11, characterised in that it further includes the steps of supplying fuel and preheated-air from a first of the pair of regenerative burners connected to the combustion chamber while exhausting the combustion products through the preheater of the other of the regenerative burners to reheat its storage material and, after a selected period, reversing the gas flow through the combustion chamber by stopping the air flow through the first preheater, introducing air into the other preheater for heating and supply to the combustion chamber and exhausting the combustion products through the first preheater to reheat its heat-storage material.
  20. A method according to Claim 14, characterised in that the flow reversal is repeated at a rate of tens of seconds to several minutes to alternate the flow through the combustion chamber.

FIG. 1  
PRIOR ART

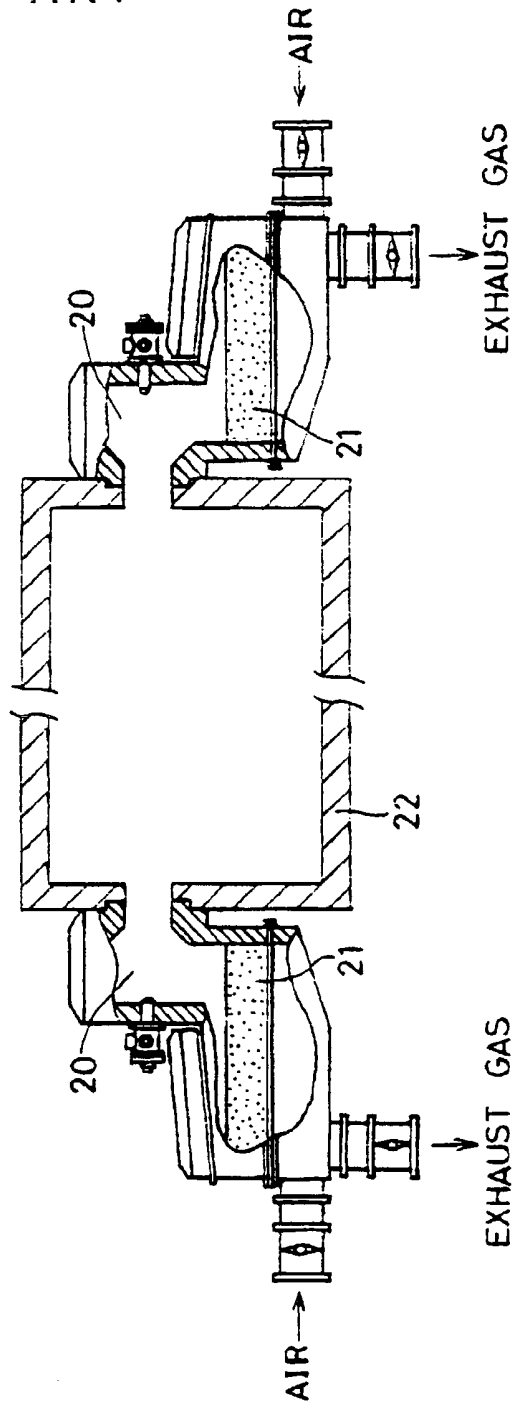


FIG. 2

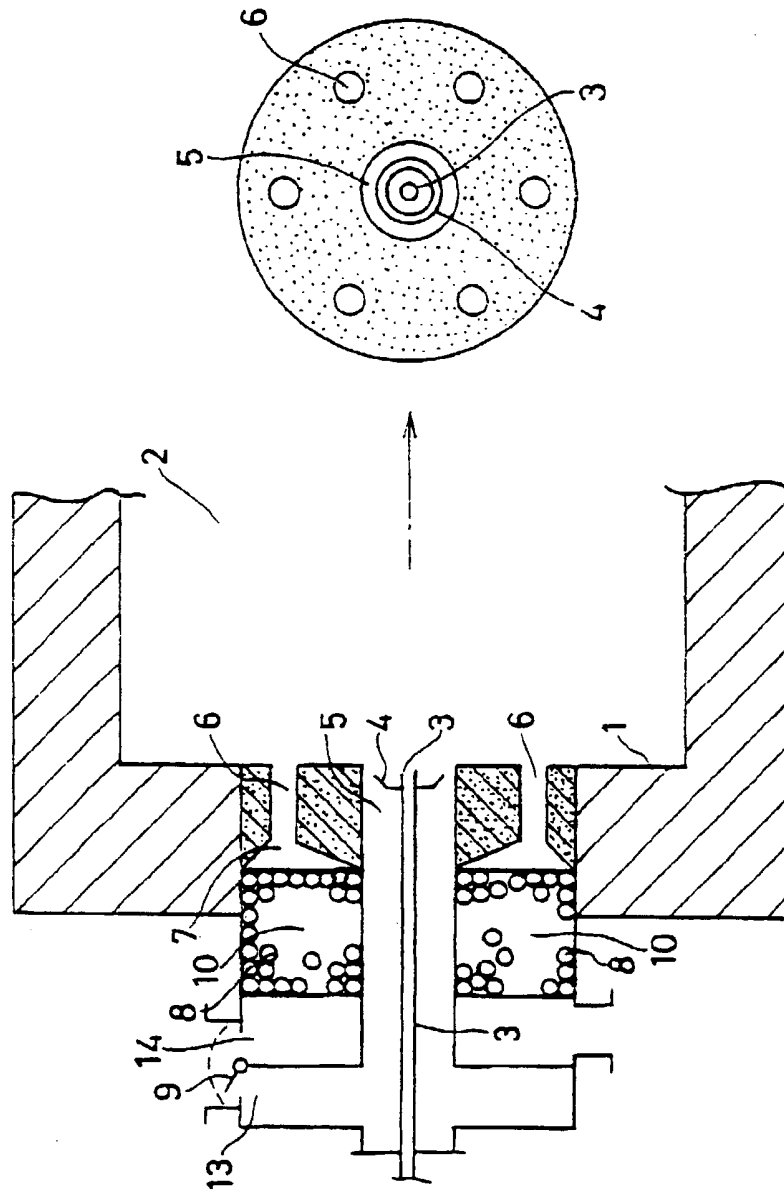




FIG. 3

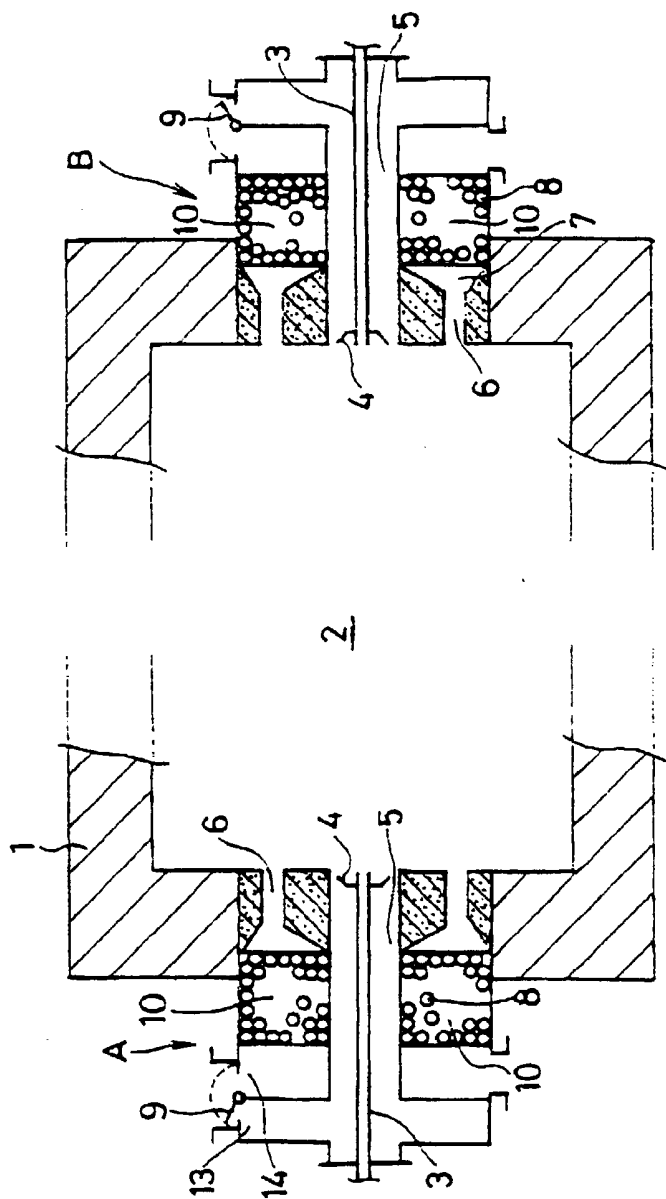


FIG. 4

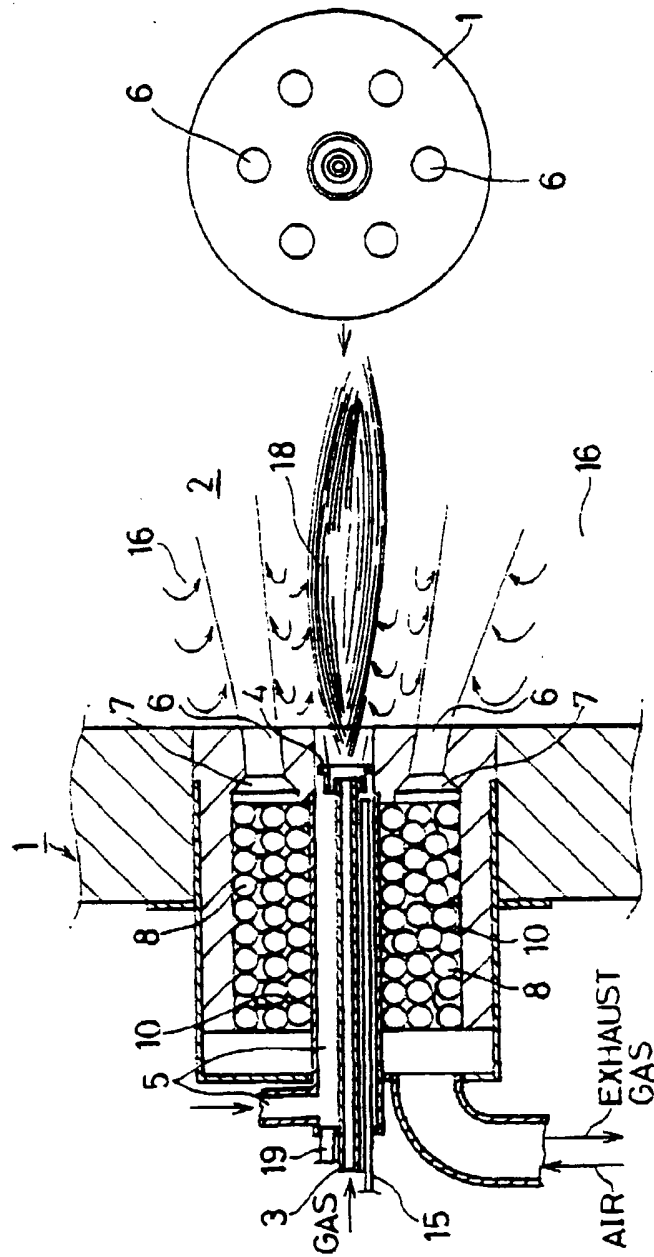


FIG. 5

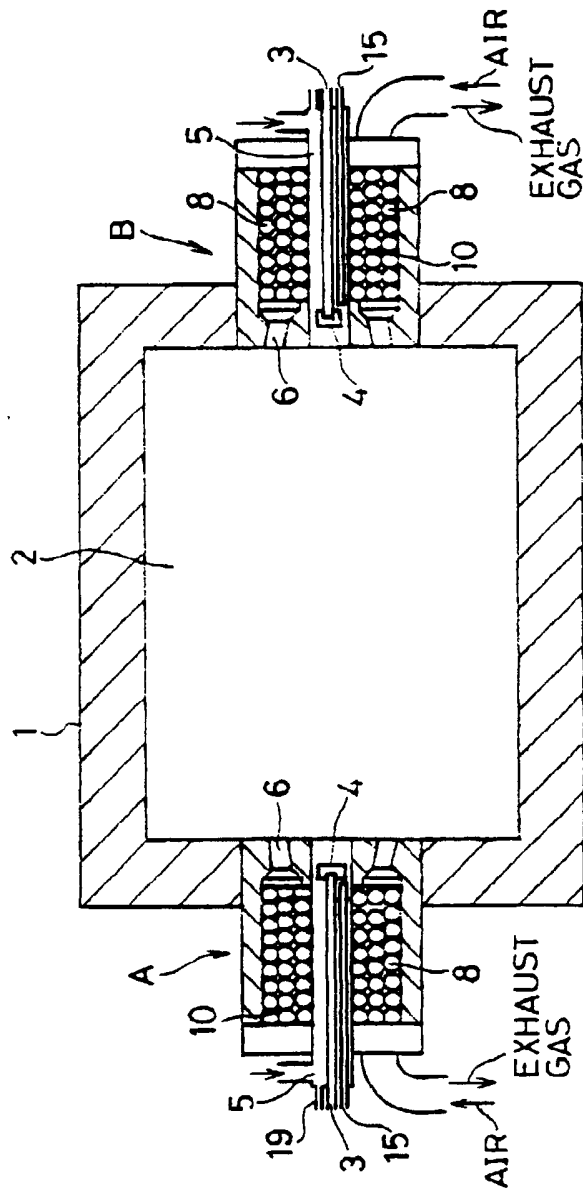


FIG. 6

